Using Systems Modeling to Facilitate the PNGV Technology Selection Process

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Motivation

- A major PNGV milestone for 1997 is for a technology selection to be made for technologies that will be used in the year 2004 PNGV concept car.
- The government has a need to understand the issues associated with the technologies being considered as part of PNGV, and to participate in the PNGV technology selection process.
- In order to better understand the challenges faced by the candidate technologies and appropriately guide future R&D, it is important for the government to use systems analysis to evaluate promising technologies.

Objectives

- Develop a ranked list of candidate PNGV drivetrain technologies and evaluate how well they help achieve the PNGV vehicle fuel economy goal of 80 mpg.
- Gather data on state-of the art component technologies
- Guide OAAT advanced vehicle development programs with unbiased hybrid vehicle component performance and system configuration assessments
- Provide validated modeling tool and analysis to OAAT to support Hybrid Vehicle Program and other OTT advanced vehicle projects and planning

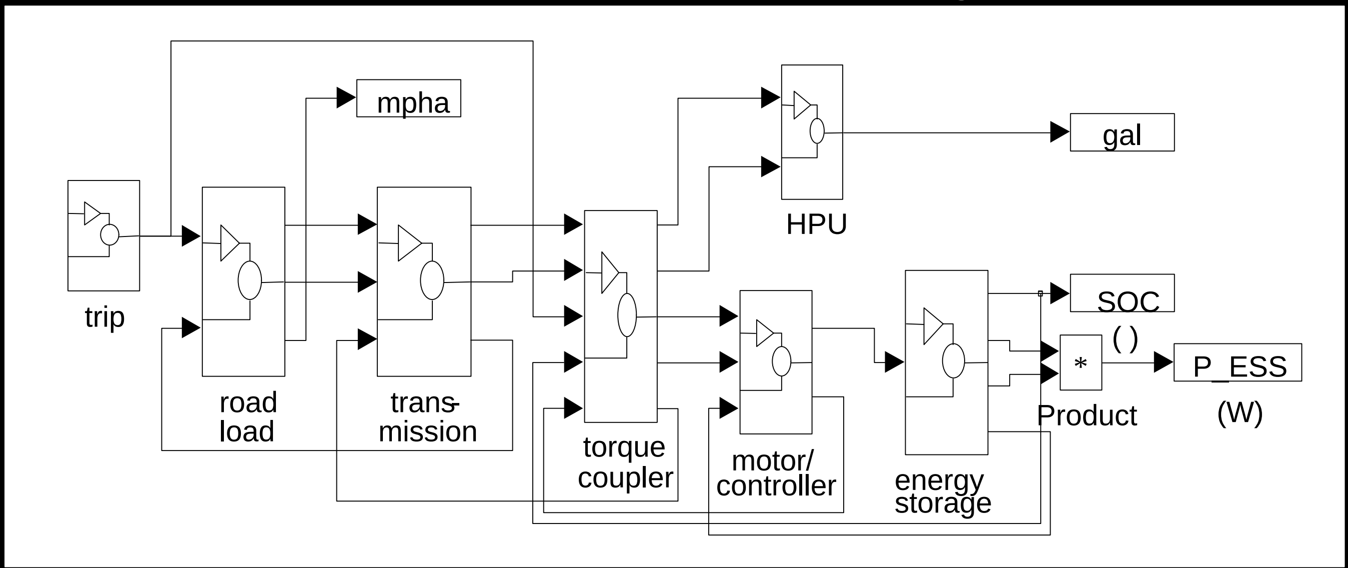
Approach

- Compile a database of state-of-the-art propulsion system components being considered for PNGV
- Consult with experts to improve existing database of components and system data
- Develop conventional, series, and parallel vehicle configurations based on component databases
- Exercise ADVISOR to predict vehicle performance, fuel economy, and average component efficiencies over urban and highway driving cycles
- Review results with industry and DOE to obtain their feedback on assumptions and results

The Simulation Tool: ADVISOR

- Developed in MATLAB/Simulink environment
- Modular: easy to modify
- Quasi-static assumption: uses component performance maps

Parallel ADVISOR block diagram



ADVISOR Model Benchmarking

- Credibility of modeling results depends on:
  - Validation of modeling methodology and equations: benchmarking against other models and test results
  - Realistic input data: obtaining accurate component data and vehicle assumptions
- ADVISOR has gained credibility in these two areas through:
  - Benchmarking ADVISOR against PNGV Systems Analysis Toolkit and internal Industry models (typically results are within 3-5%)
  - Having universities validate the model with their FutureCar Challenge hybrid vehicle test results
  - Building up the library of validated input component data from universities and government R&D programs

Automated Configuration Evaluation Process

Control strategy
- Conventional
- Parallel
- Series
- Thermostat
- Series Follower

Engine
- CIDI
- Fuel Cell
- Gas Turbine
- SIDI
- Stirling

Battery
- Li-ion
- Pb-acid

Assemble
- Select appropriate data files
- Size components to meet performance
- Build total vehicle mass

Evaluate

Compute mpg, component ηs

Output

Cycle-averaged mpg and ηs, diagnostics

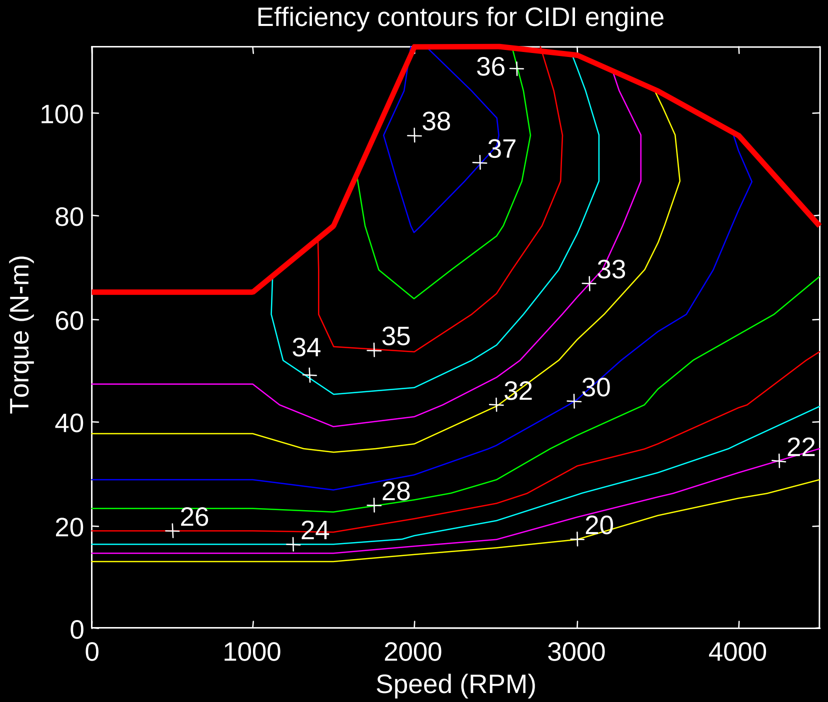
Loop through for each vehicle configuration

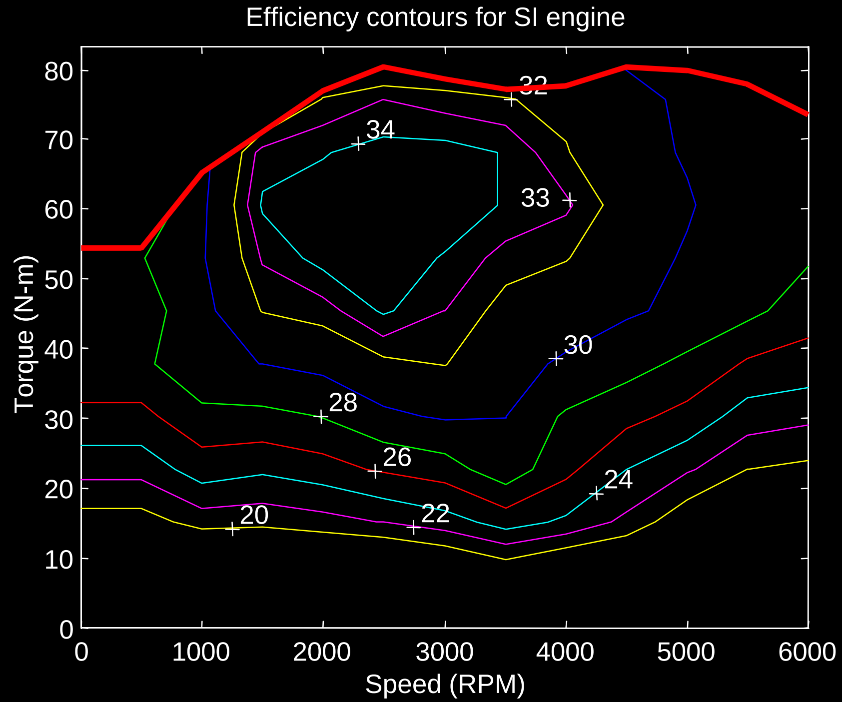
SPECIFY — "BUILD" & "TEST" — SAVE RESULTS

Assumptions: Vehicle-level

Aerodynamic Drag (C_DA)	0.4 m^2
Rolling Resistance	0.006
Regenerative Braking Fraction	0.7
Accessory Load	700 W
Glider Mass	824 kg
Final Vehicle Mass	Built up from glider mass plus component masses calculated from specific powers

Assumptions: Internal Combustion Engines





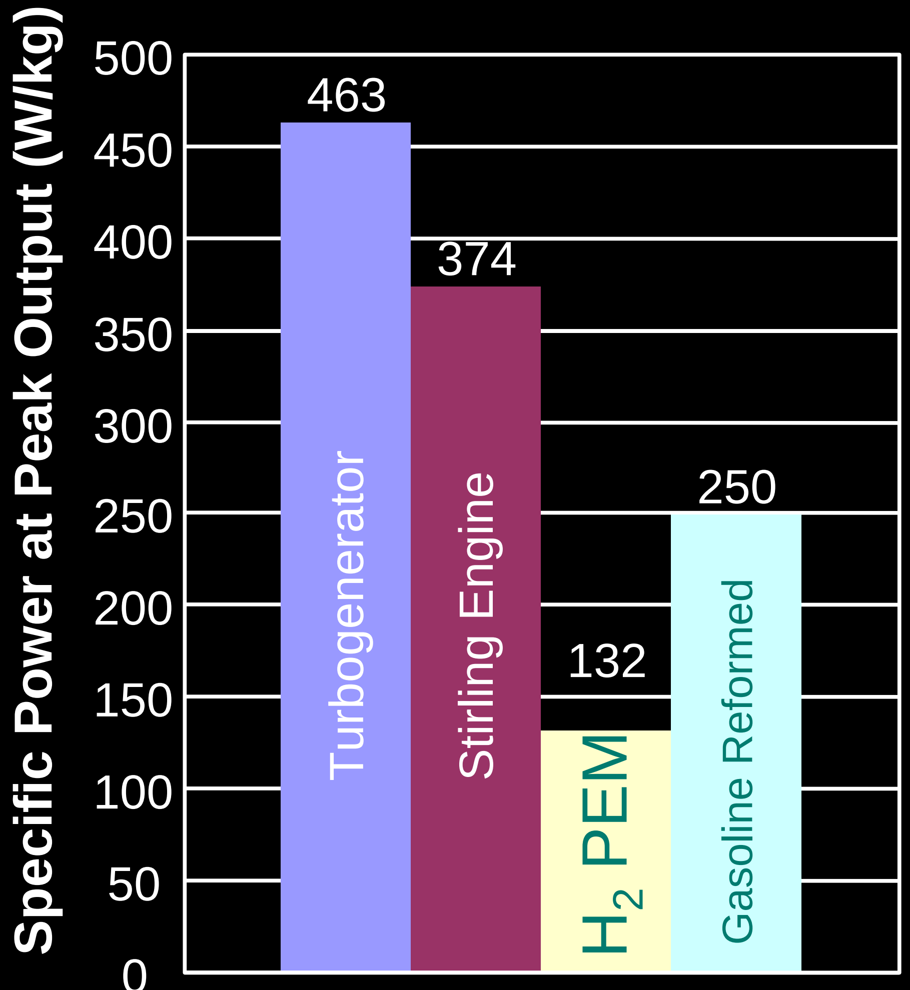
CIDI Engine
Specific Power = 324 W/kg
Peak Efficiency = 38%

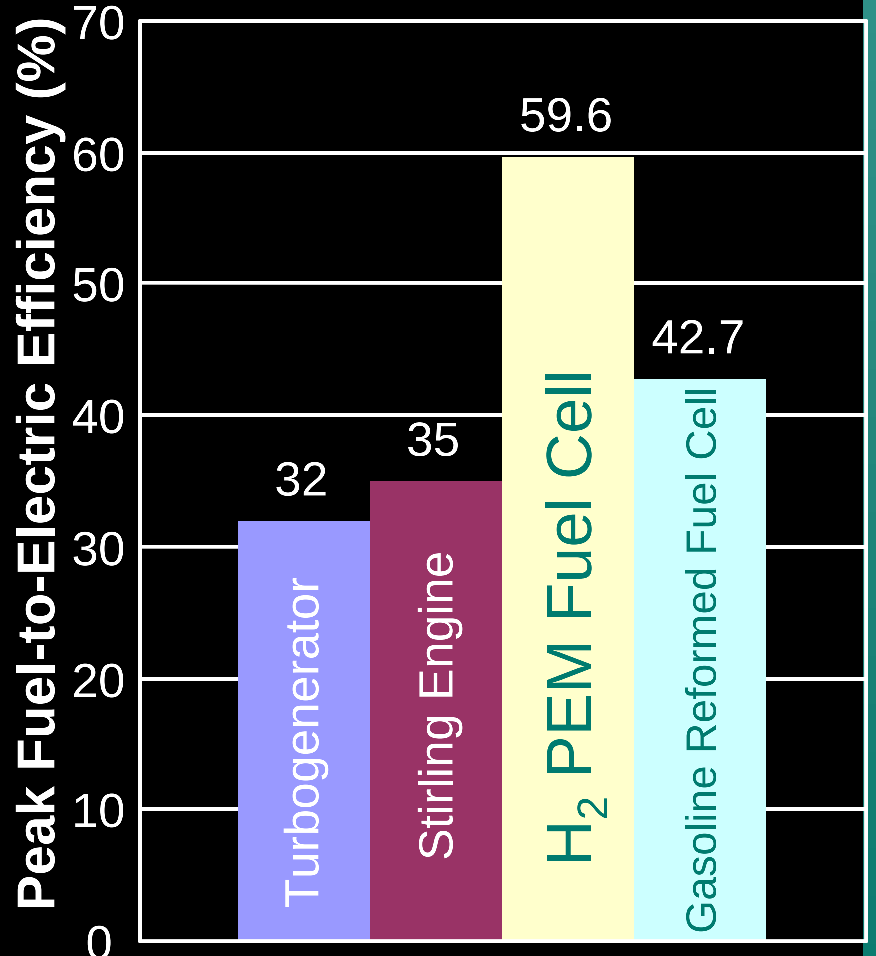
SI Engine
Specific Power = 618 W/kg
Peak Efficiency = 34%

Engines shown at scaled size for parallel hybrids

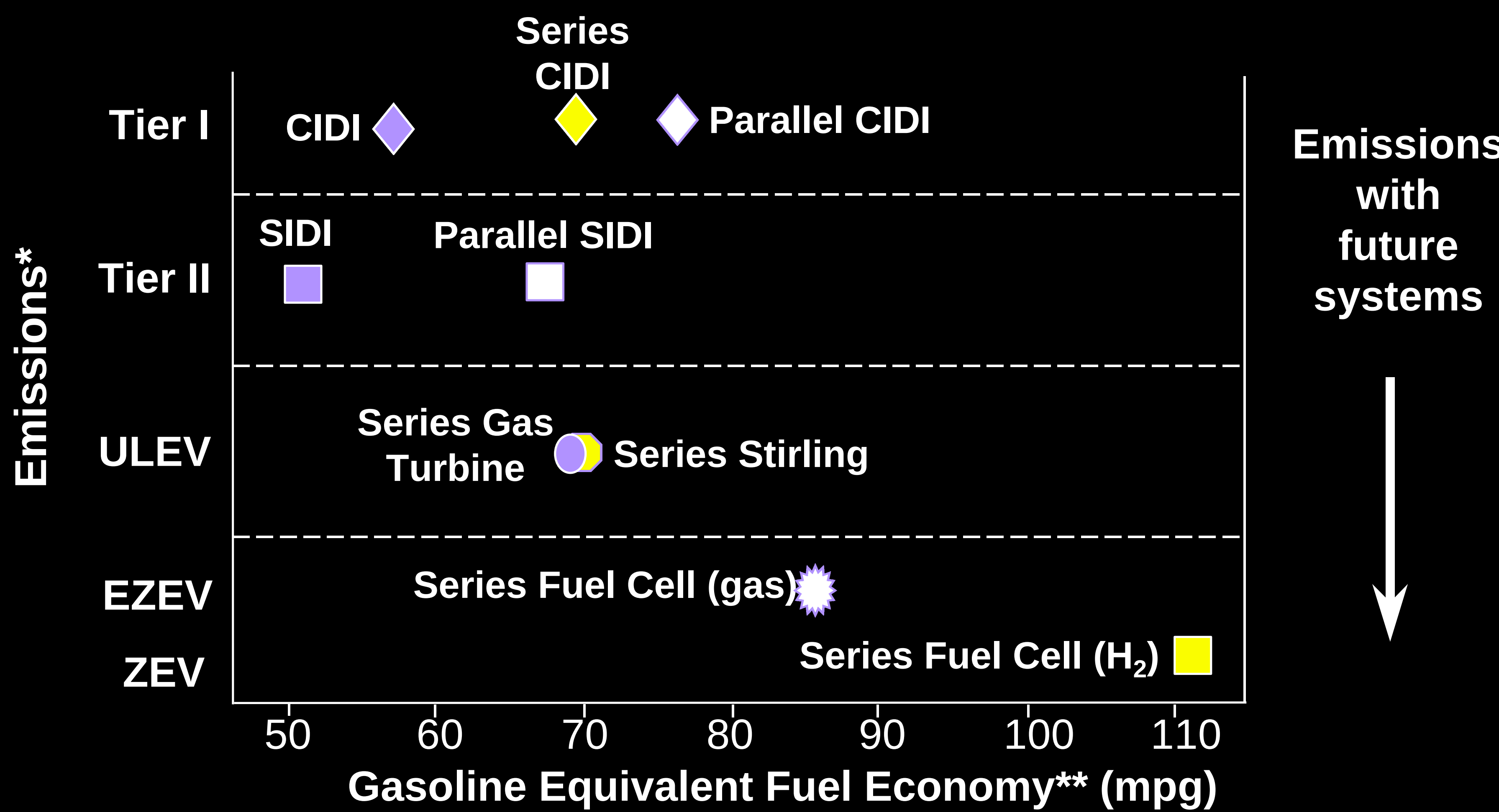
1997 Automotive Technology Development
Customers' Coordination Meeting

Assumptions: Gensets for Series Vehicles





Results: Fuel Economy & Emissions



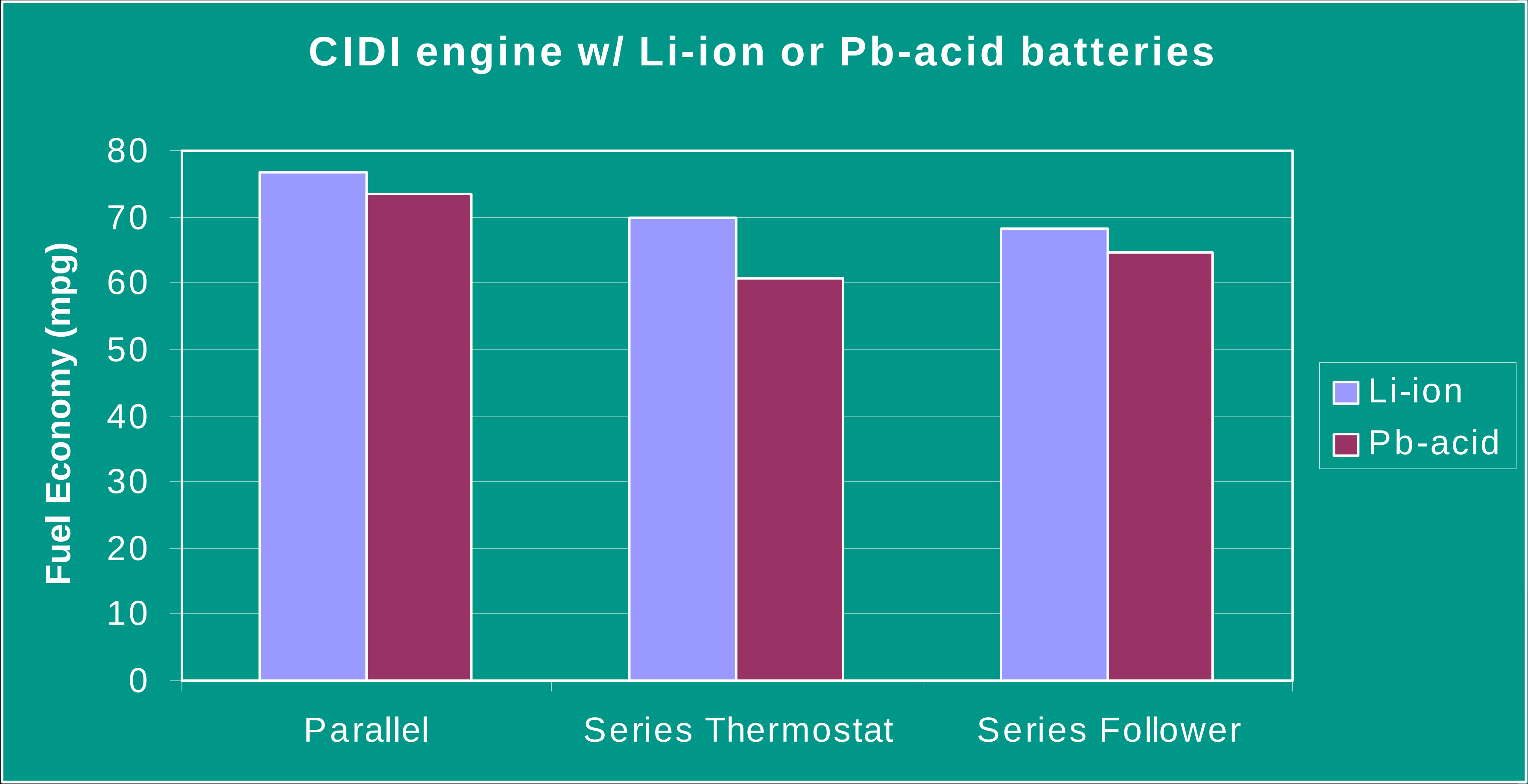
*Emissions are estimates and not from simulation results

**Fuel economy results are configuration and control strategy dependent

Results: Detailed Performance

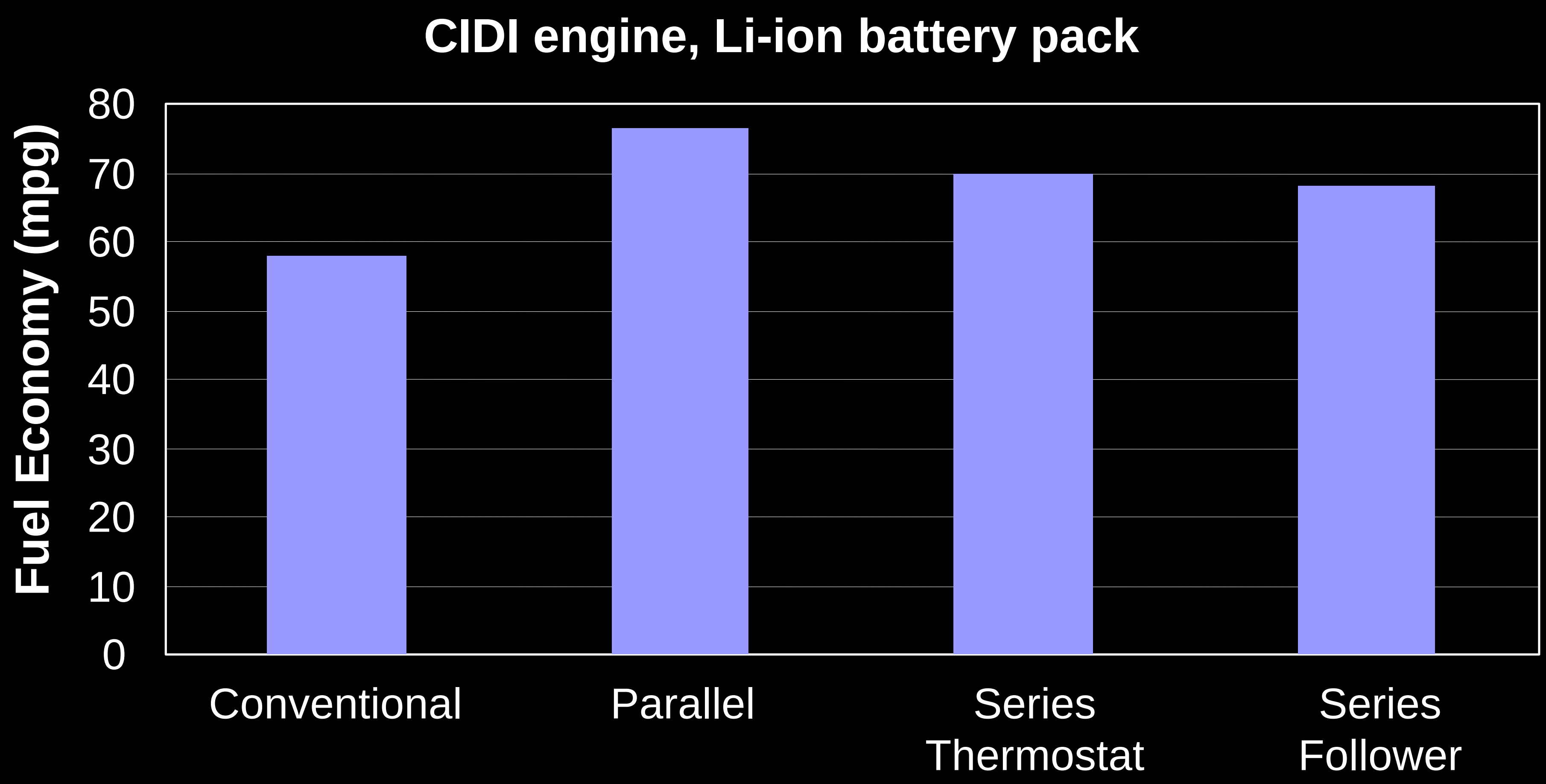
Vehicle Classification	Vehicle Type	Conventional		Parallel Hybrid		Series Hybrid: Thermostat Control Strategy				
	Engine Type	SIDI	CIDI	SIDI	CIDI	gas turbine	CIDI	Stirling	gasoline fuel cell	H2 fuel cell
	Battery Type			Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion
Fuel Economy	Urban fuel economy (mpg)	44	48	63	70	65	64	64	79	101
	Highway fuel economy (mpg)	65	79	76	87	78	79	78	97	128
	Combined Fuel Economy (mpg)	**52**	**58**	**68**	**77**	**70**	**70**	**70**	**86**	**111**
Cycle-Averaged Component Efficiencies	Engine Efficiency	24%	28%	28%	32%	32%	36%	35%	43%	60%
	Motor Efficiency			46%	78%	88%	88%	88%	88%	88%
	Motor-as-Generator Efficiency			81%	79%	85%	85%	85%	85%	85%
	Transmission Efficiency	84%	88%	84%	88%	91%	91%	91%	91%	91%
	Round-trip Regen. efficiency			18%	32%	40%	38%	38%	39%	41%
Power	Peak Engine Power (kW)	63	57	45	40	40	40	40	40	40
	Peak Motor Power (kW)			20	20	56	63	58	62	75
Mass	Vehicle Mass (kg)	913	1026	982	1059	1006	1147	1045	1135	1400
	Battery Mass (kg)			62	62	104	116	108	112	137

Discussion: Effect of battery type on fuel economy



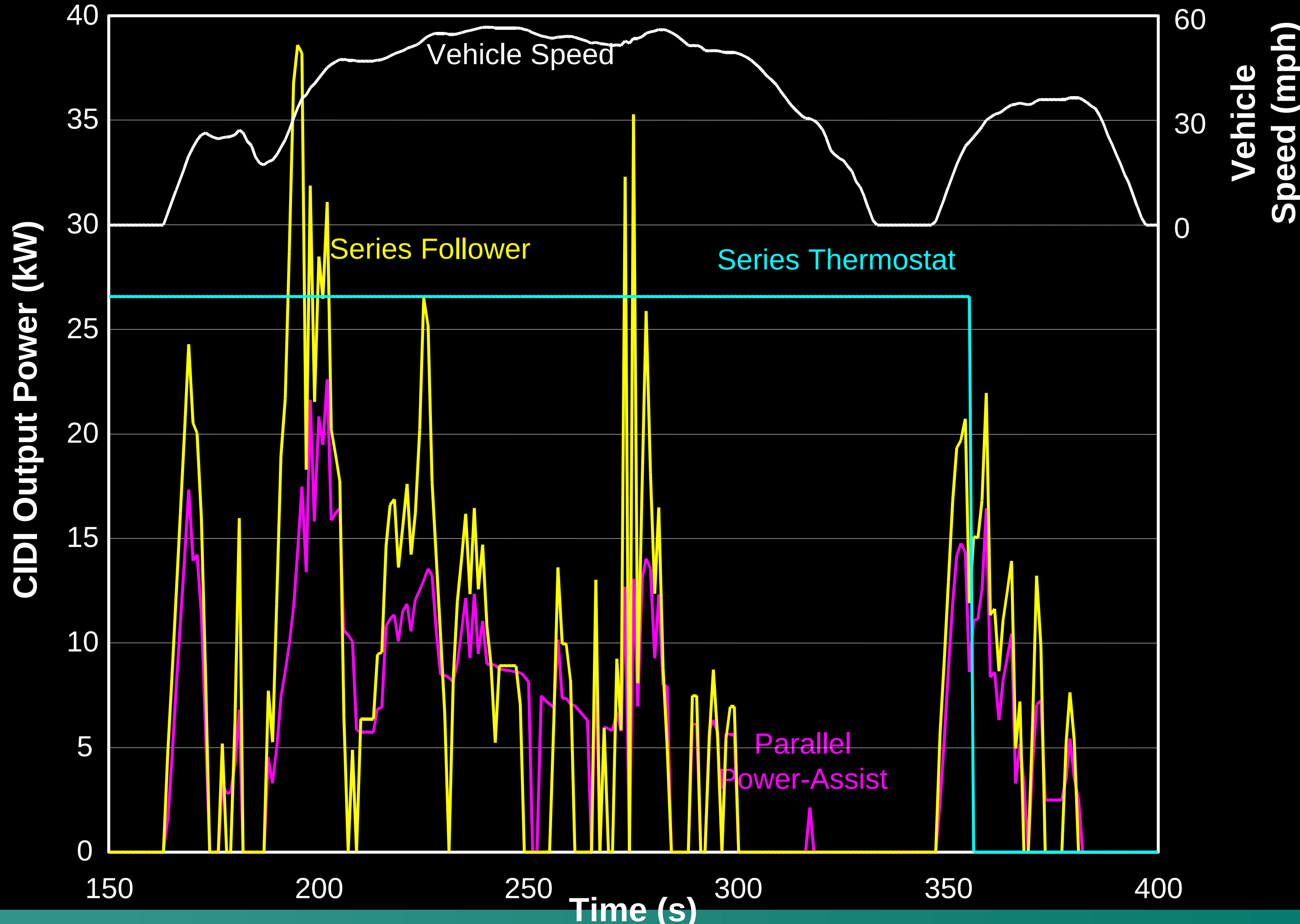
The series thermostat is most affected by a change in battery technology, going from 2nd to 3rd place fuel economy when Li-ion batteries are replaced w/ Pb-acid.

Discussion: Parallel is Most Promising for CIDI

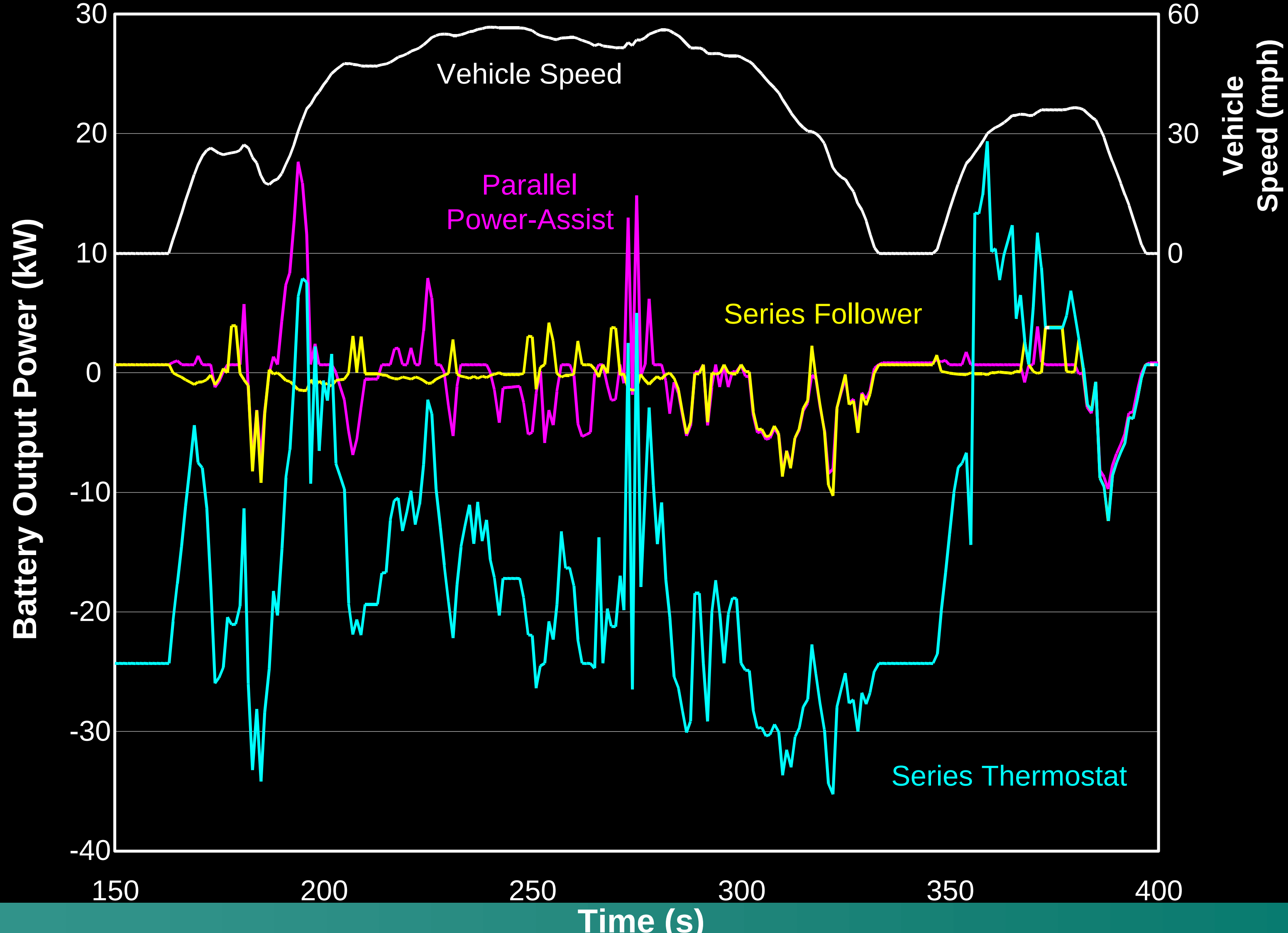


The parallel-configured CIDI achieves the highest fuel economy here, with the two series approaches roughly equally behind due to high battery efficiency minimizing their difference.

Control Strategies: Engine Power



Control Strategies: Battery Power



Interagency Collaboration

Industry

USCAR
SHARING TECHNOLOGY FOR A STRONGER AMERICA
CHRYSLER CORPORATION
Ford
GM
TASC

Government

Reinventing Government
Creating a Government that Works Better and Costs Less
Office of the Vice President
United States Department of Transportation
EPA United States Environmental Protection Agency

National Labs

ARGONNE NATIONAL LABORATORY
THE IDAHO NATIONAL ENGINEERING & ENVIRONMENTAL LABORATORY
Lawrence Livermore National Laboratory
University of California • Department of Energy
NREL National Renewable Energy Laboratory

Accomplishments

- Industry feedback was obtained to confirm input assumptions.
- 176 vehicle configurations, incorporating all candidate PNGV drivetrain technologies, were evaluated using the ADVISOR simulator.
- A ranked list of candidate PNGV drivetrain technologies was developed relative to the PNGV vehicle fuel economy goal of 80 mpg.
- The government understands the trade-offs in the PNGV Technology Selection process, and now has a means to prioritize technology development.

Future Direction

- Improve ADVISOR database of hybrid vehicle components and systems based on best available data and models.
- Validate ADVISOR against hybrid mule test data from industry hybrid propulsion system subcontracts and benchmark it against industry models.
- Improve credibility of advanced battery modeling through obtaining validated pack-level data and models.
- Evaluate and update existing technical targets.
- Support DOE and the PNGV Systems Analysis Team by performing vehicle trade-off studies and evaluating new technologies and vehicle configurations.